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DISCUSSION OF LONG-PERIOD WAVES OR SURGES IN HARBORS

(Published in April, 1952)

By John S. McNown, B. W. Wilson, and John H. Carr

HYDRAULICS DIVISION

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DISCUSSION

JOHN S. MCNOWN,[7] M. ASCE.—In his study of long-period waves in harbors, Mr. Carr calls attention to a factor in harbor design that is both important and very little understood. Such waves are commonly referred to by the French word, "seiche," in publications from England and from the European continent, and the writer recommends its adoption in American publications. The author's title serves to emphasize the need for such a term. The term, "wave," invariably requires a modifier, and the term, "surge," is frequently reserved for the moving hydraulic jump or tidal bore. A seiche can be defined as a periodic disturbance in a partly or completely enclosed body of water, the entire volume being put in motion (rather than just that portion at or near the surface), and the characteristics of the motion being closely related to the geometry of the containing basin.

Because the writer had already made theoretical and laboratory studies of seiche, he found particularly enlightening the author's discourse concerning field observations and the probable origin of disturbances having periods much greater than those of ordinary sea waves. Under the heading, "Characteristics of Long-Period Waves in Basins," the author writes about the simplest forms of two-dimensional wave patterns for rectangular basins only. Because a more general statement of the problem can be made, and because specific solutions are available for other simplified harbor forms, the writer would like to present a brief summary of this topic. In addition to the writer's work on the subject,[8,9] Lord Rayleigh,[10] H. Lamb,[11] and H. Bouasse[12] have written about seiche or mass oscillation in enclosed basins of regular shape. The problem of the two-dimensional seiche in lakes was ably treated by G. Chrystal,[13] and other papers have been written on calculations and observations for various lakes.

In common with many types of wave motion, seiche is essentially irrotational, and the motion can therefore be defined in terms of a velocity potential. The essential boundary conditions can be stated as follows: (1) The normal component of the velocity, $\partial\phi/\partial n$, must be zero at the solid boundaries; (2) the familiar free surface condition must be satisfied—namely, that the normal component of the velocity of a particle at the free surface must equal the normal velocity of the surface itself; and (3) a special boundary condition is hypothesized for the opening or entrance. In addition, the usual first ap-

NOTE.—This paper by John H. Carr was published in April, 1952, as *Proceedings-Separate No. 123*. The numbering of footnotes, illustrations, and equations in this Separate is a continuation of the consecutive numbering used in the original paper.

[7] Prof. of Mechanics and Hydraulics, and Associate Director, Iowa Inst. of Hydr. Research, State Univ. of Iowa, Iowa City, Iowa.

[8] "Sur l'entretien des eaux portuaires sous l'action de la haute-mer," by J. S. McNown, *Comptes Rendus de l'Académie des Sciences*, Paris, France, May 28, July 2, and July 27, 1951.

[9] "Waves and Seiche in Idealized Ports," by J. S. McNown, National Bureau of Standards, Washington, D. C. (publication pending).

[10] "On Waves," by Lord Rayleigh, *Philosophical Magazine*, Vol. V, 1876, pp. 257–279.

[11] "Hydrodynamics," by H. Lamb, Dover Publications, New York, N. Y., 1945, pp. 282–290

[12] "Houle, rides, seiche et marées," by H. Bouasse, Delagrave, Paris, France, 1924, pp. 92–145.

[13] "On the Hydrodynamical Theory of Seiches," by G. Chrystal, *Transactions*, Royal Soc. of Edinburgh, Vol. 46, No. 20, Part III, 1908.

proximation to the actual occurrence is made by assuming that the amplitudes of the vertical motion are small. As the details of the development, starting from this point, have been presented elsewhere,[8,10] an expression for the surface displacement η is written directly:

$$\eta = \frac{k\,T}{2\,\pi} \sin\left(\frac{2\,\pi\,t}{T}\right) F(x,y) \ldots\ldots\ldots\ldots\ldots\ldots (12)$$

in which k is a dimensional constant related to the mode of the motion, t is time, T is the period of the occurrence, and $F(x,y)$ is a function of horizontal position.

For the definition of the unknown spatial function, F, and the third boundary condition, the geometry of both the harbor and the entrance must be known or assumed. Only geometrically simple harbor forms can be analyzed without elaborate calculations. Harbor plans that are circular or rectangular can be solved in terms of ordinary functions. Additional prerequisites of a straightforward analysis are the assumption of constant depth, and walls that are vertical and totally reflecting. Although these restrictions are somewhat extreme, complete analysis of any one port form provides an insight into the characteristics of such a phenomenon. In problems as complex as this one, it is natural to work from the particular toward the general solution.

Also, a distinction must be made between two types of motion. One, which has been designated as resonant, is any one of the discrete natural motions that could be excited in the harbor even if it were enclosed on all sides. These can be likened to the various discrete modes of a taut membrane, each having a characteristic frequency. Because the frequency of the wave—or of the exciting force—can differ from any of the resonant frequencies of the harbor, another class of motions (designated as nonresonant) can also occur. For resonant motions, the component of velocity normal to the plane of the entrance is zero, so that the entrance is, in effect, a continuation of the solid boundary. The other type of motion is nonresonant, in which a periodic flow into and out of the port takes place. This latter condition is considerably more difficult to fulfil, and the characteristics of the velocity at the entrance must be assumed so as to be an acceptable approximation of the actual cocurrence in the laboratory or in nature.

For circular cylindrical basins, F is directly expressible in terms of Bessel functions. A general resonant motion is characterized by the expression:

$$F_n\,(r,\,\theta) = \cos\,(n\,\theta)\,J_n\,(k\,r) \ldots\ldots\ldots\ldots\ldots\ldots (13)$$

in which r and θ are spatial coordinates in the plane of the undisturbed surface, n is any integer, $J_n\,(k\,r)$ is a Bessel function, and the dimensional constant, k, is any one of the values that make the velocity normal to the vertical walls equal to zero. In mathematical terms, k is selected so that $\left.\frac{\partial J_n\,(k\,r)}{\partial r}\right|_{r=R} = 0$, R being the radius of the circular harbor. The period of such motions is given by the relationship,

$$\left(\frac{2\,\pi}{T}\right)^2 = g\,k\,\tanh\,(k\,h) \ldots\ldots\ldots\ldots\ldots\ldots (14)$$

in which h is the depth of the water. Thus, once a mode of motion has been selected, the corresponding value of $k\,R$ can be determined from a table of Bessel functions, and T can then be calculated for known values of g, R, and h.

For nonresonant motions, a summation of all possible particular solutions must be made so that a complete solution with a realistic boundary condition at the entrance can be obtained. Hence, F is written in general form as an infinite series of terms like the one in Eq. 13.

$$F\,(r,\,\theta) = \sum_{n=0}^{\infty} A_n \cos\,(n\,\theta)\,J_n\,(k\,r) \ldots\ldots\ldots\ldots\ldots\ldots (15)$$

The coefficients A_n can then be evaluated by means of a Fourier expansion so that the boundary condition assumed for the entrance is satisfied. Fortunately, for most motions of practical importance, the first ten terms are dominant. Therefore, an approximation can be made, if necessary, for all terms that remain after a certain number of terms have been evaluated. As they are available elsewhere, the details of such calculations are less important to this discussion than is the experimental justification of the importance and applicability of the results obtained therefrom.

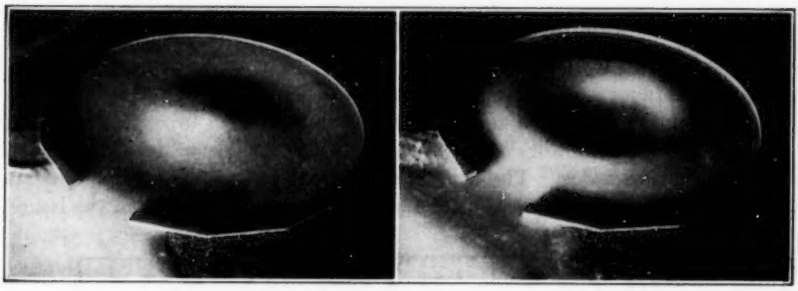

FIG 9.—RESONANT SEICHE IN A CIRCULAR HARBOR

In an experiment conducted by the writer at the Neyrpic Hydraulics Laboratory in Grenoble, France, harbors of simple geometry were constructed and a series of observations were made. Initially, a circular harbor was constructed with a radius of 1.60 m (5.25 ft) and a water depth of 16 cm (6.3 in.) was maintained. Waves were produced at one end of a channel, in which the structure had been placed; and the waves, acting through a symmetrically placed opening of one sixteenth of the circumference, produced motion within the harbor. Wave filters were used to refine the wave forms, and a beach on either side of the harbor entrance effectively eliminated the reflection of energy. Observations of the wave amplitude were made at various points inside and outside the model harbor with a specially-designed point gage.

One particularly impressive motion is shown in Fig. 9, the water having been made somewhat opaque by a suspension of starch. In this case, the Bessel function of zero order with two nodal circles was selected for the mode, the value of $k\,R$ being 7.015, so that $k = 7.015/1.60 = 4.38$ meters^{-1} (1.34

ft^{-1}), and, from Eq. 14, $T = 1.23$ sec. The theoretical profiles of maximum displacement are compared with the observed values in Fig. 10. The remarkable features of these results are the relatively large amplitudes observed and computed for the center of the harbor, and the close correspondence between the two results. For these measurements, the amplitude at the center was 3.3 times that at the wall and entrance; and—because a clapotis tends to form at the entrance—the amplitude there is nearly double that of the incident wave. For this study, the amplitude at the entrance was approximately 1 cm (0.4 in.). Other modes were perhaps less impressive but were found to possess similar characteristics.

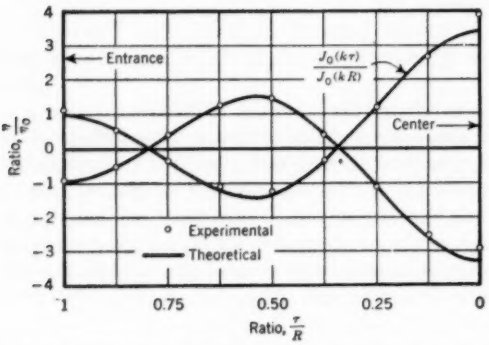

FIG. 10.—COMPARISON OF THEORETICAL AND OBSERVED AMPLITUDES FOR RESONANT MOTION IN A CIRCULAR HARBOR

Besides visual comparisons for many typical resonant motions and detailed measurements for a few, observations and calculations were made of one nonresonant motion. The value $kR = 6$ was chosen, both because it was convenient for the laboratory arrangement and because there were no resonant values near this value. The comparison between the series calculations and the measurements are shown for one half the circumference (along the boundary) in Fig. 11. The reference amplitude was computed from the characteristics of the incident wave, including its phase at the entrance. If it is considered that several approximations and assumptions had necessarily been made in obtaining the calculated curve, its correspondence with the measured

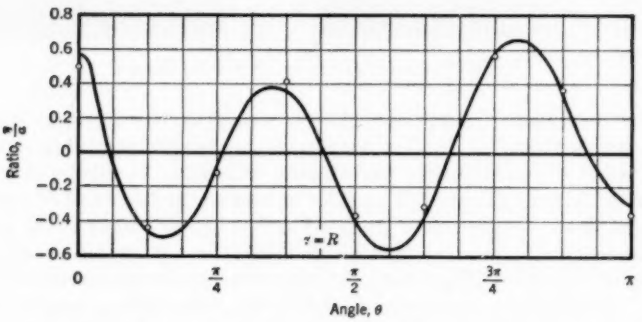

FIG. 11.—COMPARISON OF THEORETICAL AND OBSERVED AMPLITUDES FOR NONRESONANT MOTION IN A CIRCULAR HARBOR

values seems quite close. Surely the trend or mode of motion is clearly and correctly defined.

Resonant motions were also investigated for a rectangular port, the F-function in Eq. 12 being

$$F(x,y) = B \cos \frac{\pi m x}{b} \cos \frac{\pi n y}{c} \quad \ldots\ldots\ldots\ldots\ldots\ldots (16)$$

in which b and c are the dimensions of the rectangle in the x-direction and y-direction, respectively. The coefficient k, and hence the period, can be determined from the relationship:

$$\left(\frac{k}{\pi}\right)^2 = \left(\frac{m}{b}\right)^2 + \left(\frac{n}{c}\right)^2 \quad \ldots\ldots (17)$$

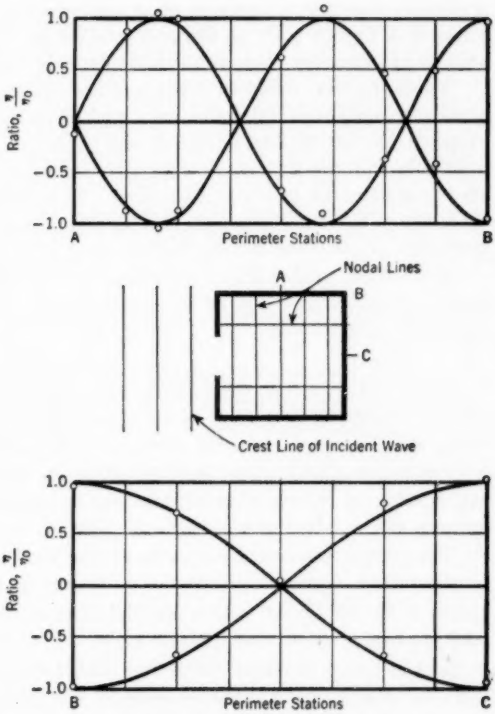

FIG. 12.—REPRESENTATIVE RESONANT MOTION IN A SQUARE HARBOR

Such motions are more general than the two-dimensional waves described by Mr. Carr, but are still restricted to discrete periods for which m and n are integers. Measurements taken for a representative motion are shown in Fig. 12, the dimensions b and c, both being equal to 3.20 meters. In this instance, $m = 2$ and $n = 5$. The nodal lines and the location of the entrance are shown in the inset. The results for the rectangular harbor are somewhat less striking than those for the circular harbor, but they are evidently as well defined. Because the positions of the nodal lines and the location of the entrance are not necessarily reconcilable, the motions in the rectangular harbor are seen to have one more degree of freedom than those in the circular harbor. This is reflected in the fact that a double summation would be necessary for the nonresonant motions in rectangular harbors.

Several characteristics of seiche in harbors having engineering importance were clarified in this somewhat idealized study. Clearly demonstrated was the

fact that seiche patterns that are characteristic of a given harbor exist, and that they can be excited as the result of a periodic disturbance at the entrance. In the absence of sufficient dissipation within the harbor, the amplitudes of these disturbances can even exceed those of the incident wave, and the disturbances will not necessarily be reduced by a reduction in the width of the harbor opening. Because the nature or mode of the motion is extremely variable with the period, harbor models should probably be studied for a considerable range of frequencies, particularly in the light of Mr. Carr's indications that very long-period disturbances can be troublesome. It is probable that the amplitude of a disturbance varies greatly from place to place in a harbor such as the one studied by the author as well as in one of simplified geometry such as those depicted in this discussion.

These studies, made in what has been called "the world's worst harbor," were obviously not intended as a model study of a proposed harbor form. Rather, insight into the nature of the basic problem was sought, as well as an evaluation of the analytical approach and the determination of the primary characteristics of seiche in harbors. The writer hopes that the foregoing definition and description of this phenomenon will be helpful in the interpretation of practical studies such as that presented by the author.

Acknowledgment.—The experiment described in this discussion was performed at the suggestion of P. Danel, A. M. ASCE, director of the Neyrpic Hydraulics Laboratory.

B. W. Wilson,[14] A. M. ASCE.—A welcome contribution has been made by the author to the literature of a subject which, from the engineering point of view, has hitherto received rather meagre attention. However, it is now blossoming out with great rapidity, largely, it would seem, as a result of the experiences of World War II and the gathering momentum in engineering opinion of the value of hydraulic models.

The writer was concerned with rather similar investigations to those cited by the author—involving, in the writer's case, Table Bay Harbor at Cape Town, Union of South Africa. A few parallel comparisons where they hinge upon the author's paper may be of interest here.

At the onset, perhaps the writer may be pardoned for correcting what he believes to be a slight misstatement by the author in regard to the harmonics of a standing-wave oscillation. He believes that it is accepted scientific usage to refer to the fundamental oscillation as the first harmonic with a nodality of one, the second harmonic having a nodality of two, and so on. This would amend the author's Eq. 3 to

$$T_n = \frac{2l}{nC} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (18)$$

in which $n = 1, 2, 3, \cdots$ represents both the harmonic order and the nodality; thus, $n = 1$ would correspond to the fundamental oscillation or first harmonic.

[14] Formerly Asst. Research Engr., Chf. Civ. Engr.'s Office, South African Railways & Harbours, Johannesburg, Union of South Africa.

Eq. 18 is attributed to J. R. Merian[15] (1828). In terms of Eq. 18, the author's left-hand Figs. 2(*b*) and 2(*c*) strictly should read "Second" and "Third" harmonics, respectively, and the statements made in the text below Fig. 7 would need a corresponding correction.

For a basin opening upon a larger body of water, such as the sea, the author's Eq. 4 should, on the same basis, read

$$T_m = \frac{2\,l}{m\,C} \qquad (19)$$

where the harmonic order, m, in this case, has the values $m = 1, 3, 5$.[16] The circumstances of this state of oscillation permit only the odd harmonics to exist, the true second, fourth, and other even-numbered harmonics being entirely suppressed. The right-hand part of Fig. 2(*b*) is thus correctly the third harmonic, and that of Fig. 2(*c*), the fifth harmonic. The right-hand part of Fig. 2(*a*) is in effect one half of the left-hand part of Fig. 2(*a*), and the right-hand part of Fig. 2(*b*) is one half of the left-hand part of Fig. 2(*c*). It is suggested that the captions for Figs. 2(*a*), (*b*), and (*c*) might better have been written "Fundamental (or First) Mode," "Second Mode," and "Third Mode," respectively, the use of the word "mode" implying essentially the manner of oscillation.

The author mentions that a resonant amplification factor between 1 and 2 for long waves appears to be an average for typical harbors. This statement seems to be based on the relation between the wave-heights just outside the confines of a harbor, and those within, but the writer would point out that the wave-heights of long waves, when measured anywhere near a linear boundary, are themselves increased by the wave reflections. It is virtually impossible to judge the original heights of long waves at, or near, a boundary, because the long wave can exist in that region only as a standing-wave system, whose theoretical amplification factor (assuming no energy loss on reflection) is 2. Thus, by the time a disturbance has produced resonance inside a harbor (and here the author's amplification factor of 1 to 2 enters) the true amplification of the original wave may be anything from 2 upwards.

At Table Bay Harbor, it can be shown that just outside the harbor no less than six systems of standing waves, formed by incident waves and first reflections, can coexist as a result of the ingress into Table Bay of a single train of long waves from the outer ocean. The incoming waves divide around Robben Island (which is some 3 miles offshore in the approach to Table Bay), and converge on the harbor from two directions; when the external swell direction is favorable, the three standing-wave systems induced by each set of incident waves come into phase to give a theoretical amplification factor of 6 outside the harbor. Each set of three standing waves involves the incident waves and two reflections (shoreline and harbor) twice over. Hence, the theoretical magnification of $[(3 \times 2) + (3 \times 2)]$ is halved to yield 6. The writer cites this behavior outside the harbor to illustrate the probability that the true resonant

[15] "The Oceans," by Sverdrup, Johnson, and Fleming, Prentice-Hall, Inc., New York, N. Y., 1942, p. 539.

[16] "Hydrodynamics," by Horace Lamb, University Press, Cambridge, England, 1932, p. 267.

amplification factor for the interiors of most harbors, referred to a point reasonably remote from the harbor, exceeds 2.

The term "seiche," not used by the author, denotes resonance or near-resonance oscillations (both forced and free) in a basin, as distinct from non-resonant oscillations (such as individual standing waves), and the writer would emphasize the advantage of its adoption in the terminology of this subject.

The author's statements concerning the large horizontal displacements of the water particles possible at the nodes of long-period seiches in harbor basins can be confirmed from the experience in Table Bay Harbor in 1940, when a large ship displacing 42,000 tons, tied at the center berth along the short side of a long rectangular basin, broke all her moorings and ranged to and fro through approximately 20 ft (according to report). At the time, the ship was lying in a depth of 43 ft of water at the node of the fundamental transverse oscillation for the dock, which has a period of about 1.8 min. A tide gage at the antinode of this transverse seiche registered a height range (h) for this periodicity of 18 in. Calculation shows that the maximum water particle displacement in a 1.8-min seiche of this magnitude is about 11 ft, which would account for the major part of the movement of the ship; the remainder probably derived from the influences of superposed second and third harmonic transverse oscillations, which commonly occur.

The writer strongly supports the author in his belief that long-period wave trains, as distinct from surf beats, are a frequent cause of harbor surging. The Munk theory of surf beats has now received additional support from British investigators,[17] and it would appear that this form of surge must be considered a reality unless the phenomenon is in some way merely a manifestation of an underlying series of long waves which are part of the short-period, high-amplitude wave group, but which lag the latter in the manner found for surf beats. The possibility of this being true is at least suggested by the theoretical digressions of Lord Kelvin[18] on the form of the front and rear of a free procession of waves in deep water. Fig. 13, which is reproduced from Lord Kelvin's paper,[18] but in which the underlying long-wave system was inserted by the writer, indicates that a procession of waves having a surface profile at both front and rear similar to Fig. 13(a), would at a time 25 wave-periods later, assuming progression to the right, have the front and rear configurations shown respectively by Figs. 13(b) and 13(c). In Fig. 13(b), which shows the attenuation of the group in long waves, point A has advanced from the origin at the full wave velocity; point B has advanced from the origin at only half the wave velocity. In Fig. 13(c), point C has advanced from the rear origin at the full wave velocity; point D has advanced at half the wave velocity. The comparison between front and rear is illuminating; the undulating effect in the latter is found to reside in the expansion through the wave group from the rear (dash-line curve, Fig. 13(c)) of the underlying "push-pull" wave, P-Q, which initially defines the junction of the wave group with still water (see Fig. 13(a)). The underlying wave of Fig. 13(c) was obtained by "residuating" the surface

[17] "Surf Beats: Sea Waves of 1 to 5-Minute Period," by M. J. Tucker, *Transactions*, Royal Soc. of London, Series A, Vol. 202, August, 1950, pp. 565–573.

[18] "On the Front and Rear of a Free Procession of Waves in Deep Water," by Lord Kelvin, *Mathematical and Physical Papers*, Cambridge, England, Vol. IV, No. 36, 1910, pp. 351–367.

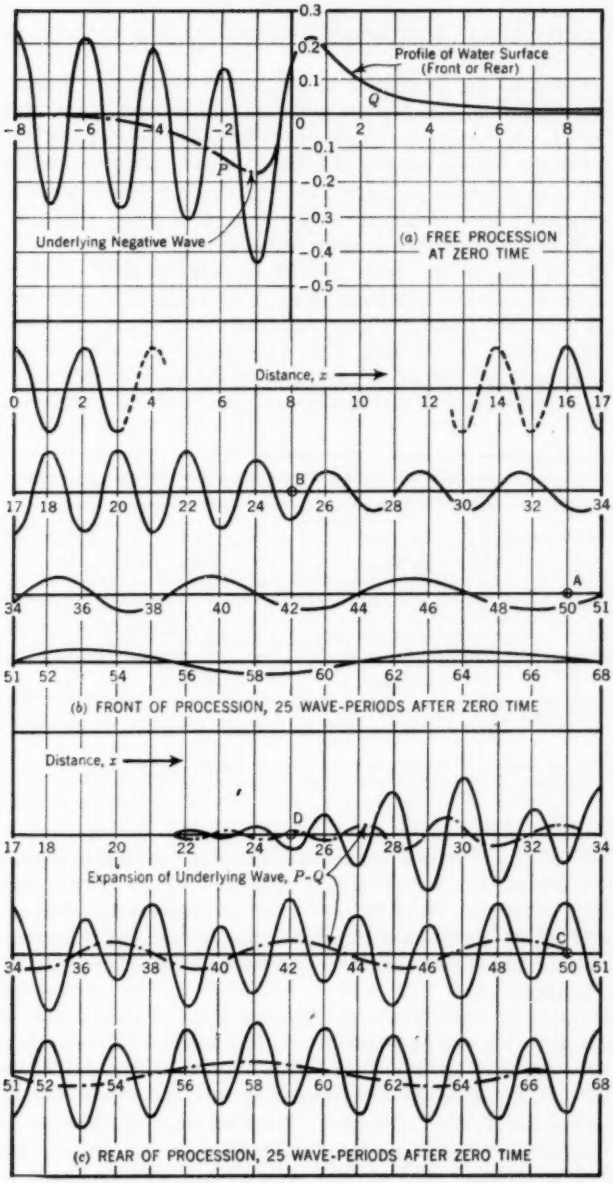

FIG. 13.—THE FORM OF THE FRONT AND REAR OF A FREE PROCESSION OF SINUSOIDAL WAVES IN DEEP WATER

profile with respect to the main sinusoidal wave, the residual being found similar in all respects to Lord Kelvin's separate analysis of the expansion of a single "push-pull" wave.

With respect to the incidences of surging in Table Bay Harbor, there is now clear evidence of association with traveling depressions of the South Atlantic Ocean, which skirt the coast of the Cape of Good Hope on southeasterly courses. Although harbor surging is always accompanied by swell conditions, many cases were recorded at Cape Town in which prominent swells failed to produce surging. This condition would seem to suggest that the surf beat alone cannot explain the phenomenon in the general case.

At Cape Town, it has been proved repeatedly that small barometric fluctuations in the overlying atmosphere—in generally calm and clear weather, but with a winddrift from the open sea (northwest)—are capable of exciting strong oscillations in Table Bay with consequent powerful surging through the harbor entrances. Fig. 14 is furnished in evidence of this and shows the obvious dependence of the sea oscillation upon the barometric disturbance.

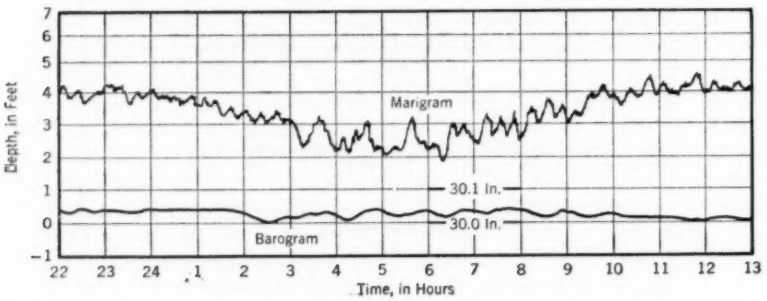

Fig. 14.—Marigram for Duncan Basin, Table Bay Harbor, Cape Town, With Superposed Barogram, September 30–October 1, 1945 (Slight Northwest Wind)

The barometric fluctuations have been analyzed frequently for inherent periodicities and have shown a curious consistency in indicating the presence of harmonically related waves having apparent periods within the ranges of from 55 min to 66 min, from 28 min to 36 min, and from 15 min to 17 min. Significantly, these periods are closely similar to some of the natural periods of oscillation for Table Bay, as determined theoretically, graphically, and from marigram analyses.

Range action at Cape Town, as affecting ships at their berths (which the surging shown in Fig. 14 does not do), is characterized by a different sort of trace on the tide gage of which Fig. 15 is a typical example. The absence of much local wind or barometric fluctuation in this case shows that the disturbances must have come from far away. The wide range of resonant periodicities normally found in different parts of the harbor on an occasion such as this would seem to indicate that exciting ground swells of many periods usually accompany the visible swells. Just as local barometric fluctuations are capable of inducing coastal seiches, so must distant meteorological disturbances

(particularly the barometric oscillations near the centers and along the cold fronts of the traveling depressions) be capable of exciting long ground swells in addition to the high surface waves which the strong winds in these distant areas tend to generate. A want of space precludes presentation of the many other arguments and supporting facts that justify the view that long waves have a real identity in the undulations of the sea.

The author has concluded by recommending a program of investigation directed toward defining the critical periods of the resonance of moored ships under the stimulus of seiches. It would appear that at the time of writing he was unaware that this study, to some extent at least, had already been begun.[19] It is therefore interesting to find that the author's and the writer's observations on this subject led to parallel conclusions regarding the importance of the ship's mooring-line system.

It appears that the likelihood of oscillations with periods as great as 3 min being really critical for moored ships at the NOB, is debatable in the light of the writer's analysis (which indicated that critical periodicities could generally be expected in a range less than 2 min). However, much could depend on the

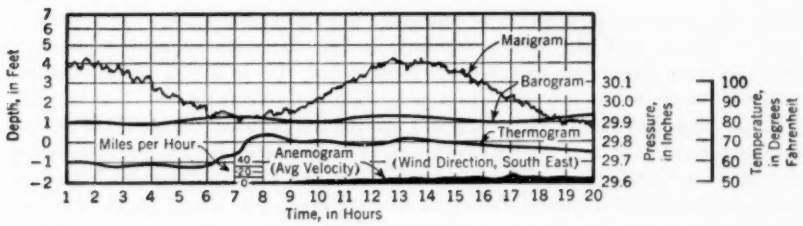

FIG. 15.—MARIGRAM FOR DUNCAN BASIN, TABLE BAY HARBOR, CAPE TOWN, WITH SUPERPOSED BAROGRAM, THERMOGRAM, AND ANEMOGRAM, DECEMBER 17–20, 1946

size of the ships at the NOB, and the types and conditions of moorings. One gratifying aspect in support of the writer's analysis is the author's account of the immunity shown by ships at the NOB to the very strong 6-min surges created by the Alaskan earthquake. The inference is that the longer-period resonance frequencies, such as show great prominence in the author's Fig. 7, are of less practical consequence than are the smaller resonance peaks in the higher frequency range. The conclusion that the greatest effort should be concentrated upon reducing the magnitudes of seiches having periods less than 2 min, and to a lesser extent those with periods from 2 to 4 min, has been the guiding principle adopted in seeking a solution to the Cape Town problem.

One other conclusion reached at Cape Town is borne out by Fig. 7 of the author's paper. This pertains to the fact, shown by the Terminal Island model studies, that the effectiveness of restricting the gate opening is usually least for long wave periods. It is an inescapable fact that narrowing a basin entrance will be of very little help in controlling long-period surging, especially of the type shown in the writer's Fig. 14, and these surges, in general, must be tol-

[19] "Ship Response to Range Action in Harbor Basins," by B. W. Wilson, *Transactions*, ASCE, Vol. 116, 1951, pp. 1129–1157.

erated. The earlier statement that they are of less practical consequence than the periodicities below, for example, 4 min, is only partly true, because certain of the long-period surges (depending on the seiches in the outer embayment) cause such strong reversal currents through the basin entrances that they constitute a potential danger to the navigation of large ships.

JOHN H. CARR[20].—An interesting addition to the paper has been made by Mr. McNown in his indications of the extent to which mathematical analysis may be applied to the problem of basin oscillation. It is unfortunate that the typical complicated geometry and appreciable damping of harbors preclude the immediate applications of such analysis to many practical problems. The growing evidence that the effect of long-period waves is most serious for the period range of from 1 min to 2 min indicates that analytical work should be directed at harbor response to waves of this period. Consideration of harbor depth and size then will indicate which harmonics of basin oscillation are most significant; in typical cases these will be the third, fourth, or higher harmonics.

Mr. Wilson has called attention to the writer's nonstandard terminology with respect to the numbering of harmonic modes of oscillation. This error is acknowledged, and the writer concurs in Mr. Wilson's suggested changes. Both Messrs. McNown and Wilson recommend the adoption of the French "seiche" to designate the oscillation of a basin in a natural mode. At the risk of appearing provincial, the writer still prefers the phrases "long-period wave" for the general case, and "basin oscillation" for the particular case; first, because resonant oscillation is not necessary for damaging ship motions, and, second, because the straightforward description of the motion as a resonant oscillation of the water mass immediately recalls similar behavior in mechanical, acoustical, and electrical systems. The mental picturing of such analogies cannot help but have a beneficial effect in understanding the particular case of basin oscillation.

The writer's observation of maximum amplification factors of less than two is with reference to harbors characterized by a large basin connected to the sea by a small opening, as by a gap in the protecting breakwater. For harbors of this general plan, it will be appreciated that the exciting wave height is greatly attenuated because of diffraction through the harbor entrance. Thus, an amplification factor of one, with reference to the height of the exciting wave outside the harbor entrance, may still represent a very large increase in the height of waves incident on a reflecting boundary within the harbor.

Mr. Wilson's remarks on the subject of the origin of long-period waves in the sea are of great interest. It is to be hoped that this phenomenon will be further explored by meteorologists and oceanographers, and will eventually become subject to accurate forecasting.

The writer is especially gratified by Mr. Wilson's comments on the importance of the ship mooring system in determining the engineering significance of long-period wave motion in harbors. The writer is currently (1952) engaged

[20] Senior Research Engr., Hydrodynamics Lab., California Inst. of Technology, Pasadena, Calif.

in a study for the Bureau of Yards and Docks of the Department of the Navy, in which a continuously recording direct measurement system is being used to determine the forces in a ship's mooring lines. This study is directed primarily at the development of information on loading conditions for the structural design of mooring structures, but it also may be expected to yield further data on the response of moored ships to periodic water forces.

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